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Effects of Transit Temperatures and Modified Atmospheres on Market Quality of Lettuce Shipped in Nitrogen-Refrigerated and Mechanically Refrigerated Trailers

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Effects of Transit Temperatures and Modified Atmospheres on Market Quality of Lettuce Shipped in Nitrogen-Refrigerated and Mechanically Refrigerated Trailers

By J. K. Stewart, horticulturist, and M. J. Ceponis, plant pathologist,
Market Quality Research Division, Agricultural Research Service

SUMMARY

Transit temperatures and market quality of western lettuce were studied in test shipments made from California to east coast markets in piggyback trailers. Comparisons were made between trailers in which liquid nitrogen was used both to refrigerate the load and to modify the atmosphere and trailers with conventional mechanical refrigerating systems and normal atmospheres.

Average transit temperatures were 36° F. in the nitrogen (N) trailers and 39° in the conventional (MR) trailers. Average temperature variation within the loads was about 2° to 3° in both types of trailers. The N trailers had some freezing of lettuce in certain parts of the load, and the MR trailers had some refrigeration equipment failures. The N trailers provided reduced but not controlled oxygen (O_2) atmospheres during transit. The O_2 concentration in N trailers in which O_2 recorders were installed averaged 3.3 and 3.8 percent.

Market quality of lettuce from both types of trailers was generally satisfactory at destination. Butt discoloration was slightly less severe at time of arrival in lettuce shipped in the N trailers than in the MR trailers. This slight difference disappeared after a 4-day holding period at 50° F. Decay also was less prevalent in lettuce from the N than from the MR trailers. These differences in market quality were probably due to the lower transit temperatures in the N trailers rather than to the modified atmosphere. The low O_2 atmosphere in the N trailers significantly reduced russet spotting in the one test in which this disorder occurred to an appreciable extent.

INTRODUCTION

In 1966 a report[1] was published on the results of transcontinental test shipments of lettuce in piggyback trailers (TOFC-trailer on flatcar), in which the atmosphere had been modified by introducing nitrogen into the load compartment. In one of the systems tested, liquid nitrogen provided both atmosphere modification and the sole means of refrigerating the trailer. This system, which had no fan for air circulation, caused excessively high load temperatures and excessive temperature variations within the loads. Certain modifications in this equipment have since been made, including the installation of a nitrogen-powered pneumatic fan at the front end of the load compartment.

This 1967 report gives the results of subsequent tests with lettuce shipped in this more recent version of the nitrogen-refrigerated piggyback trailer as compared with the conventional piggyback trailer.

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[1] Stewart, J. K., Harvey, J. M., Ceponis, M. J., and Wright, W. R. Nitrogen--Its Effect on Transit Temperatures and Market Quality of Western Lettuce Shipped in Piggyback Trailers. U.S. Dept. Agr. Mktg. Res. Rpt. 759, 14 pp. 1966.

Eight paired trailer shipments of vacuum-cooled lettuce were made from California to east coast markets from August through December 1967 (table 1). The August and September shipments were made from either Watsonville or Salinas and the December shipments from Blythe. All but two test trailers were unloaded at New York City. The trailers loaded at Watsonville and Salinas were moved over the road to Oakland, Calif., where they were placed on flatcars. The trailers at Blythe were loaded directly on flatcars at the shipping point.

One trailer of each pair in a shipment was a liquid nitrogen-refrigerated (N) trailer; the other was a conventional mechanically refrigerated (MR) trailer. In the former the nitrogen was dispensed through a spray header tube running along the top right side of the trailer. A storage tank, holding 2,700 pounds of liquid nitrogen, was located in the nose of the trailer. A single low-velocity, nitrogen-powered pneumatic fan, with a capacity of about 1,200 to 1,400 c.f.m., was installed in the front end near the ceiling of the load compartment. The fan was operated continuously after it was activated, and its operation was independent of the nitrogen used to refrigerate the load from the spray headers at the ceiling.

Table 1.--Trailer type, shipping dates and points, and destinations for test shipments of lettuce from California to east coast markets--1967

Trailer No.	Trailer type[1]	Shipping		
		Date	Point	Destination
1.......	N	Aug. 2 ...	Watsonville	New York, N.Y.
2.......	MR	....do....	....do....	Do.
3.......	N	Aug. 3 ...	Salinas...	Do.
4.......	MR	....do....	....do....	Do.
5.......	N	Aug. 9 ...	Watsonville	Do.
6.......	MR	....do....	....do....	Do.
7.......	N	Aug. 29 ..	Salinas...	Do.
8.......	MR	....do....	....do....	Patterson, N.J.
9.......	N	Sept. 6 ..	Watsonville	New York, N.Y.
10.......	MR	....do....	....do....	Do.
11.......	N	Sept. 12 .	....do....	Do.
12.......	MR	....do....	....do....	Do.
13.......	N	Dec. 5 ...	Blythe....	Do.
14.......	MR	....do....	....do....	Philadelphia, Pa.[2]
15.......	N	Dec. 27 ..	....do....	New York, N.Y.
16.......	MR	....do....	....do....	Do.

[1] N, liquid nitrogen refrigeration; MR, conventional mechanical refrigeration.
[2] Trailer diverted en route from New York destination.

During warm weather the nitrogen used to power the fan in the N trailers was vaporized in a floor vaporizer, which provided additional refrigeration to the lower layers of the load. During cold weather the nitrogen flow was diverted to an external vaporizer to reduce the hazard of freezing near the floor. This diversion of nitrogen was automatically controlled by an internal thermostat with the sensing bulb under the floor. The load thermostat in the N trailers was at the ceiling. The load thermostat in the MR trailers was in the air return behind the bulkhead at the front of the trailer.

Transit temperatures were obtained with recording thermometers placed in the center of lettuce cartons at the following locations throughout the load: In the middle and top layers at the front; in the bottom, middle, and top layers at the half-length; and in the top layer at the rear of the trailers. All recording thermometers were in the center row. An additional recording thermometer was attached to the ceiling, usually near the rear of each trailer at centerline, to record inside air temperatures. Lettuce temperatures also were measured manually at various positions during both loading and unloading. One trailer in each pair had a thermometer attached to the undercarriage to record outside temperatures.

The oxygen (O_2) concentration in the N trailers was lowered initially by the same system used to refrigerate the trailer in transit. In five of the eight N trailers the nitrogen used to power the fan was exhausted into the load compartment, but in the other three trailers it was exhausted outside this compartment (see table 3). The nitrogen exhaust was regulated manually before shipment.

Atmosphere data for most of the trailers are limited to O_2 and carbon dioxide (CO_2) determinations of samples taken before shipment and at destination. Atmosphere samples were drawn from the load compartment through a 1/4-inch plastic tube that led outside this compartment, usually through a floor drain. Since previous tests[2] showed that the O_2 and CO_2 concentrations are very uniform throughout a load of lettuce, the location of the sampling tube in the load compartment is unimportant.

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[2] Stewart, J. K., and Harvey, J. M. Temperatures, Relative Humidity, and Atmosphere Composition in a Mechanically Refrigerated Car and a Trailer Loaded With Lettuce. U.S. Dept. Agr. ARS 51-13, 8 pp. 1967.

At shipping point, atmosphere samples were taken primarily from the N trailers, but at destination they were taken from both the N and MR trailers. O_2 and CO_2 concentrations were determined with an Orsat-type gas analyzer for most samples. For a few, a Fyrite gas analyzer was used.

During transit continuous O_2 concentrations were recorded only in N trailers 1 and 5. The recording instruments were provided by the Linde Co.

The N trailers had only a small metal air duct extending about 2 feet from the fan. The MR trailers had flexible air ducts extending almost to the rear of the load compartment.

Lettuce in the test cartons for each pair of trailers was selected from the same field to assure a comparable product. Head firmness averaged the same, firm to very firm, in test lots used in both types of trailers. The six test cartons used in each trailer were located in the same positions as the six thermometers placed in the load.

Quality evaluations of the lettuce in the test cartons were made at arrival and after a simulated marketing period of 4 days at 50° F. One layer of lettuce in each carton was used for the arrival examination and the remaining layer for the second examination. The arrival examination was made on the day of unloading or as soon as possible after unloading. When the paired trailers were unloaded on different days, the test cartons from the first trailer were held in the laboratory at 36° or 38° until test cartons from the other trailer were unloaded. Usually the delay was no longer than overnight. However, lettuce from N trailer 7 had to be held in the laboratory for 2 days at 38° before the test cartons from the companion MR trailer 8 could be unloaded and examined.

The delays that sometimes occurred before the arrival examination could be made were unfortunate, as quality differences in the lettuce that might have been apparent on arrival probably diminished by the time the first examination could be made.

External appearance of the heads was rated as follows: 1, unsalable; 2, poor; 3, fair; 4, good; and 5, excellent. Each head was completely torn apart to detect the incidence of decay, russet spotting, pink rib, tipburn, rib discoloration, or any other disorder. Only heads with a disorder serious enough to be considered objectionable to the consumer were counted.

Weight loss during transit was determined in trailers 13, 14, 15, and 16 by weighing the test cartons after vacuum cooling and at time of arrival.

Data were analyzed statistically using the analysis of variance. In most analyses, data from each pair of trailers were considered a replication. When data were available from only one or two pairs of trailers, each test carton in these trailers was considered a replication.

Two of the eight MR trailers had malfunctioning refrigeration equipment, which resulted in excessively high load temperatures and loss of the loads from decay. Therefore, quality data from the lettuce in these two paired shipments are not included in tables 4 and 5 and these data were not included in the statistical analyses. Neither are the transit temperatures from these two paired shipments included in the averages discussed in the text.

All quality examinations were made by personnel of the U.S. Department of Agriculture's Market Pathology Laboratory at Belle Mead, N.J.

RESULTS

Transit Temperatures in Liquid Nitrogen-Refrigerated and Conventional Trailers

Transit temperatures of individual trailers are shown in table 2 and figures 1 and 2. The average load temperature during transit was 36° F. in the six N trailers and 39° in the six companion MR trailers. The average difference between the coolest and warmest positions (omitting trailers 5, 6, 11, and 12) was 3° in the N trailers and 2° in the MR trailers (table 2). The average maximum temperature at destination was 38° in the N trailers and 43° in the MR trailers.

Test loads of lettuce in both the N and MR trailers averaged 36° F. after vacuum precooling (table 2).

Table 2.--Transit temperatures of lettuce shipped in liquid nitrogen-refrigerated (N) and conventional mechanically refrigerated (MR) trailers

Trailer No.	Trailer type	Average temperature after precooling	Average transit temperatures						Maximum temperature at destination[1]
			Inside air at ceiling	Load average	Coolest position	Warmest position	Outside air		
							Average low	Average high	
		° F.	° F.	° F.	° F.	° F.	° F.	° F.	° F.
1.........	N	34	....	35	33	38	64	88	38
2.........	MR	34	33	40	38	42	64	88	43
3.........	N	34	36	37	36	37	66	88	43
4.........	MR	34	36	36	35	38	66	88	41
5.........	N	36	34	36	35	37	58	86	38
6[2]........	MR	37	46	42	41	43	58	86	....
7.........	N	33	36	36	36	37	54	84	39
8[3]........	MR	34	42	43	42	44	54	84	46
9.........	N	37	33	34	29	36	57	82	38
10.........	MR	37	36	37	35	38	57	82	44
11.........	N	42	36	38	36	39	....	....	40
12[2]........	MR	40	60	52	48	55	....	....	96
13.........	N	38	34	37	36	38	34	45	37
14.........	MR	35	37	39	38	40	34	45	40
15.........	N	36	30	34	33	35	16	26	33
16.........	MR	36	36	38	37	38	16	26	41
Average[4]	N	36	34	36	34	37	....	....	38
	MR	36	37	39	38	40	....	....	43

[1] Manual lettuce temperatures obtained by U.S. Dept. Agr. personnel during unloading.
[2] Faulty refrigeration equipment.
[3] Thermostat apparently out of calibration.
[4] Data omitted for trailers 5, 6, 11, and 12 because of refrigeration failures in MR trailers.

Temperatures during transit are shown in figures 1 and 2 for trailers shipped during warm and cool weather, respectively. Average load temperatures were lower in the N than the MR trailers during both warm and cool weather except trailers 3 and 4, in which the difference was only 1°. The thermostat in MR trailer 8 was probably out of calibration, as this load averaged 43° F. during transit (fig. 1 and table 2). MR trailer 14 showed a sudden rise in temperature between the fourth and fifth day for some unknown reason.

Average transit temperatures in the N trailers were closer to the optimum for lettuce than those in the MR trailers. However, some freezing of lettuce occurred in N trailers 5, 7, 9, 11, and 15, most of it in the rows adjacent to the walls and both at the top and bottom layers of the load. Some freezing also was noted near the top center row of the trailer.

Freezing in the top layers was usually near the nitrogen pipeline and discharge nozzles. In most of the test trailers the clearance between the top of the load and the ceiling was only about 4 inches at the time of loading. The top wall-row cartons, therefore, were within about 2 inches of the nitrogen pipeline and discharge nozzles. Freezing in the bottom layers at the side rows must have been caused primarily by the cold air settling down the side walls.

Because most of the freezing occurred in the wall rows, the coolest temperatures indicated for the N trailers in table 2 and figures 1 and 2 do not necessarily reflect the temperature at the coldest part of the N trailer loads, as the recording thermometers were all in the center row of the loads.

Cartons in the wall rows in conventionally refrigerated cars and trailers have also been found to be cooler (1° F.) than those in the center row.[3]

In the five N trailers in which freezing occurred, about 20 to 76 cartons per trailer were involved, or an average of about 43 cartons per trailer. About 6 percent of the cartons, therefore, were affected, but not all the heads in these cartons were frozen.

Atmosphere Modification in Trailers

During the night of loading for the seven N trailers in which atmospheres were taken, the O_2 concentration ranged from 1.5 to 11.5 per-

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[3] See footnote 2, p. 2.

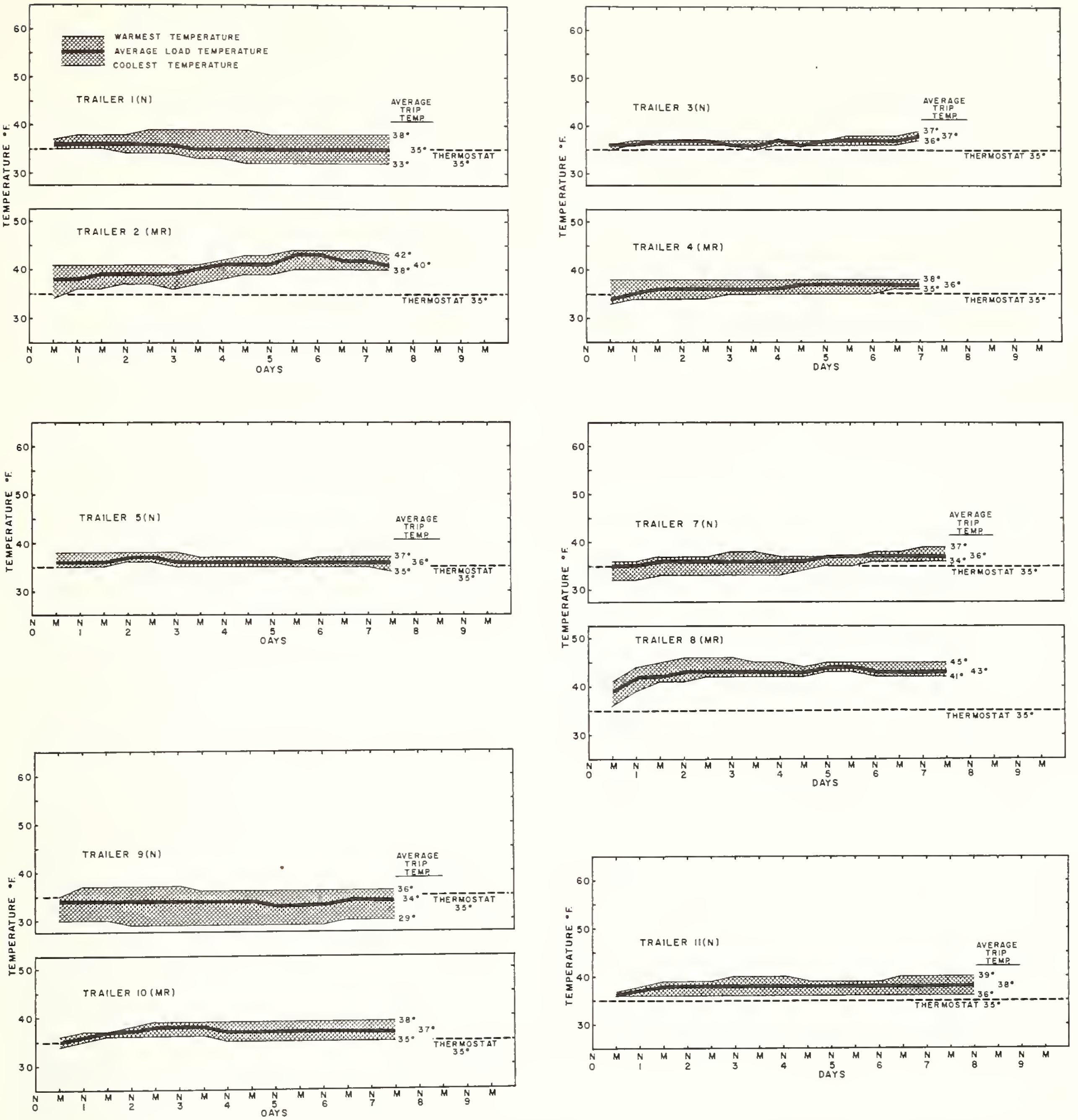

Figure 1.--Transit temperatures of lettuce shipped during warm weather in piggyback trailers (TOFC) with liquid nitrogen refrigeration (N) and with mechanical refrigeration (MR). [See table 1 for shipping dates and points of departure and destination.] Warmest, coolest, and average temperatures were recorded at 12-hour intervals during transit.

cent and averaged 7.1 percent (table 3). O_2 concentration was taken only in MR trailers 6 and 12 on the night of loading, because no modification would be expected in these trailers in such a short time. As expected, the O_2 level was almost normal, 20 percent, in these two trailers. CO_2 accumulation during the night of loading was negligible in both the N and MR trailers.

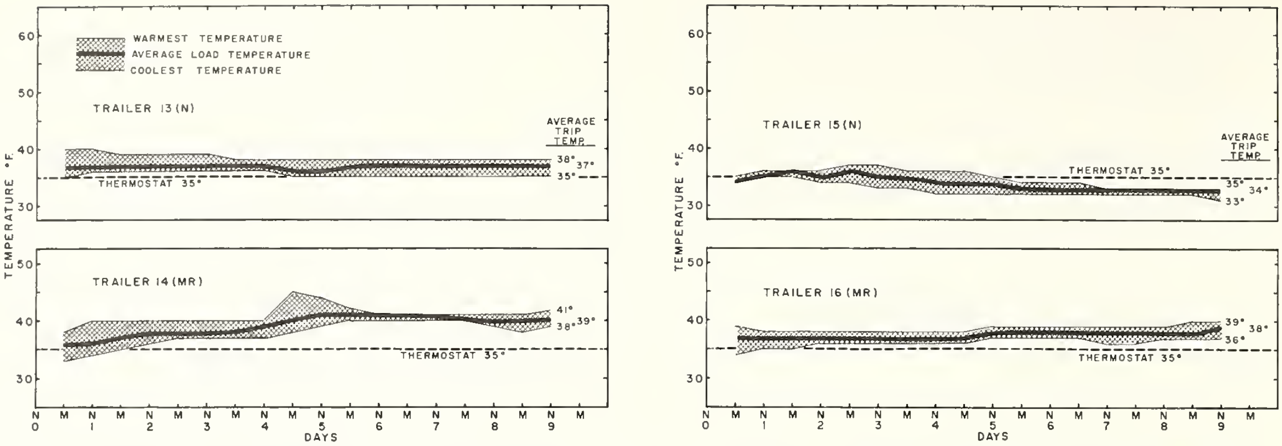

Figure 2.--Transit temperatures of lettuce shipped during cool weather in piggyback trailers (TOFC) with liquid nitrogen refrigeration (N) and with mechanical refrigeration (MR). [See table 1 for shipping dates and points of departure and destination.] Warmest, coolest, and average temperatures were recorded at 12-hour intervals during transit.

Table 3.--Oxygen (O_2) and carbon dioxide (CO_2) concentrations in test trailers of lettuce shipped from California to east coast markets[1]

Trailer No.	Trailer type[2]	Atmosphere composition at--				Nitrogen vented[3]	
		Shipping point		Destination			
		O_2	CO_2	O_2	CO_2	Inside	Outside
		Percent	Percent	Percent	Percent		
1......	N	4/ 5.0	4/ 0	0.6	0.5	X	....
2......	MR	......	......	18.8	1.3	......	....
3......	N	4/ 8.5	4/ 0	.4	.9	X	....
4......	MR	......	......	14.3	5.5	......	....
5......	N	4/ 11.5	......	.4	.2	......	X
6......	MR	4/ 20.0	......	14.7	5.5	......	....
7......	N	......	......	1.9	.4	......	X
8......	MR	......	......	15.6	3.7	......	....
9......	N	4/ 1.5	4/ .5	2.2	.2	X	....
10......	MR	......	......	....	...	......	....
11......	N	4/ 11.0	4/ .4	1.4	.4	......	X
12......	MR	4/ 19.8	4/ .5	....	...	......	....
13......	N	8.2	.5	1.2	.3	X	....
14......	MR	......	......	18.1	1.5	......	....
15......	N	4.3	0	20.5	1.0	X	....
16......	MR	......	......	15.0	5.0	......	....

[1] Atmosphere data taken by U.S. Dept. Agr. personnel with Orsat-type gas analyzer.

[2] N, liquid nitrogen refrigeration; MR, conventional mechanical refrigeration.

[3] Nitrogen used to power pneumatic fan exhausted either inside or outside load compartment.

[4] Data obtained by Linde Co. personnel during night of loading.

At destination, the O_2 concentrations in the N trailers averaged about 1.1 percent. (The O_2 level in trailer 15 was excluded because the nitrogen supply was almost depleted at destination.) The O_2 concentration in N trailers 1, 3, and 5 was less than 1 percent at destination. The O_2 concentration in the MR trailers at destination ranged from 14.3 to 18.8 percent and averaged 16.1 percent.

CO_2 concentrations in the N trailers at destination ranged from 0.2 to 0.9 percent and averaged 0.4 percent (omitting trailer 15 in which the nitrogen was almost depleted.) At destination, the CO_2 level in the MR trailers ranged from 1.3 to 5.5 percent and averaged 3.8 percent.

In N trailer 1, the increase in O_2 after about 7 hours from loading was probably caused by the control panel door being opened for control examination and adjustment (fig. 3). The increase in O_2 to normal ambient levels (21 percent) at about 70 hours in this trailer was probably due to someone leaving the control panel door open by mistake. The increase in O_2 concentration at about 120 hours was caused by the control panel door being opened for nitrogen refueling at Chicago. The O_2 level was below 1 percent in N trailer 1 for about 95 hours during transit and it averaged 3.8 percent for the total time in transit (fig. 3).

In N trailer 5, the O_2 increase at 60 hours probably occurred at Denver from someone opening the control door for inspection (fig. 3). The O_2 peak at about 110 hours occurred at Chicago during control inspection and nitrogen refueling. The O_2 level in this trailer was below 1 percent for about 42 hours and it averaged 3.3 percent for the total time in transit.

Although the O_2 levels in trailers 1 and 5 increased considerably at times during transit (fig. 3), the load temperatures were not appreciably affected (fig. 1).

The O_2 concentration in N trailer 7 was 2.2 percent when it was measured at Chicago.

Over half the test heads of lettuce from N trailers 1 and 3 had wrapper leaf lesions that appear to have been low O_2 injury. Most of the lesions were small, sunken, gray or brown

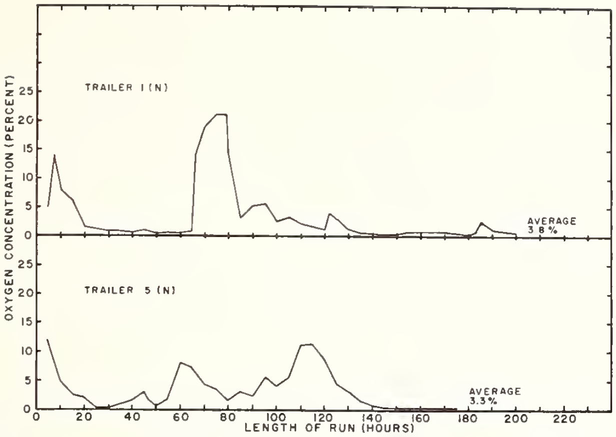

Figure 3.--Oxygen concentrations in load compartments of liquid nitrogen (N) trailers 1 and 5 shipped from California to New York City. Data from Linde Co.

areas, which were predominantly on the distal half of the affected wrapper leaves. These lesions were not found in lettuce from any of the other N or MR test trailers. The O_2 level was below 1 percent in N trailers 1 and 3 at time of arrival and below 1 percent in N trailer 1 for about 95 hours (4 days) during transit. It is not known how many hours the O_2 level in trailer 3 was below 1 percent. No low O_2 injury was found in N trailer 5, in which the O_2 level was below 1 percent for about 42 (2 days) hours.

From the limited O_2 concentration data during transit obtained in these shipping tests, it appears that physiological injury may develop on the wrapper leaves of lettuce when the O_2 concentration is below 1 percent for about half the time required for a rail shipment from the west coast to reach the east coast.

Lipton[4] found that lettuce was injured when held in an atmosphere of 0.25 percent O_2 for 1 week, and he suggested that the O_2 concentration should be at least 1 percent to preclude the danger of tissue damage.

The CO_2 levels in two of six MR trailers were 5.0 and 5.5 percent at destination. Although continuous CO_2 levels of 5 percent or higher can injure lettuce,[5] no injury that could be attributed to high CO_2 concentration was observed in the test lettuce.

Market Quality of Lettuce Shipped in Liquid Nitrogen-Refrigerated and Conventional Trailers

The external appearance of lettuce either with or without wrapper leaves was the same in both the N and the MR trailers at destination (table 4). At time of arrival, lettuce from both types of trailers was rated "fair" with wrapper leaves attached and "fair to good" after the wrapper leaves were removed. Lettuce from both the N and MR trailers deteriorated significantly during the 4-day period at 50° F. but not at the same rate. Among the lots examined after removal of the wrapper leaves, lettuce that had been shipped in MR trailers deteriorated slightly more during the 4-day period than that shipped in N trailers (significant at 5-percent level).

Butt discoloration (table 4) was slightly less severe at time of arrival (significant at 5-percent level) in lettuce shipped in the N than in the MR trailers. This effect was probably due to the lower transit temperatures in the N trailers rather than to the low O_2 levels, or it may have been due to a combination of low O_2 atmospheres plus lower transit temperatures.

In other tests, Stewart and Harvey[6] reported a significant correlation between butt discoloration and the temperature at which lettuce was held. After 10 days at 35° F., butt discoloration was rated as a "trace." At 39°, it was rated as "moderate." Lipton[7] found that butt discoloration of lettuce was slightly less severe in 0.5 and 1 percent O_2 than in air.

After 4 subsequent days in air at 50° F., the severity of butt discoloration in the current tests was the same in lettuce from both types of trailers. Lipton[7] also found that several days' storage at 50° in air completely masked any differences in butt discoloration that existed immediately after removal of lettuce from storage at low (1 percent or less) or normal O_2 levels.

Decay at destination was significantly less prevalent in lettuce from the N trailers than from MR trailers (table 5). Also, decay increased more during 4 days at 50° F. in lettuce from the MR trailers than from the N trailers.

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[4] Lipton, W. J. Market Quality and Rate of Respiration of Head Lettuce Held in Low-Oxygen Atmospheres. U.S. Dept. Agr. Mktg. Res. Rpt. 777, 9 pp. 1967.

[5] Watada, A. E., Morris, L. L., and Rappaport, L. Modified Atmosphere Effects on Lettuce. Fruit and Veg. Perishables Handling Conf. Proc., Univ. Calif., Mar. 23-25, pp. 82-85. 1964.

[6] See footnote 2, p. 2.

[7] See footnote 4.

Table 4.--Market-quality ratings of lettuce after shipment in liquid nitrogen-refrigerated (N) and conventional mechanically refrigerated (MR) trailers[1]

Time of examination	Trailer type	External-appearance rating[2]		Butt-discoloration rating[3]
		With wrapper leaves	Without wrapper leaves	
Arrival........................	N	3.1	3.5	3.0
	MR	3.1	3.6	3.6
4 days after arrival[4]..........	N	2.6	3.2	4.6
	MR	2.6	3.0	4.6
Statistical significance:[5]				
Trailer type (T)............................		NS	NS	*
Examination (E)............................		**	**	**
T × E....................................		NS	*	**

[1] Analysis based on 6 test pairs of trailers because of equipment failure in 2 of 8 MR trailers.
[2] 1, unsalable; 2, poor; 3, fair; 4, good; 5, excellent.
[3] 1, none; 2, trace; 3, slight; 4, moderate; 5, severe.
[4] Held at 50° F.
[5] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.

This reduction in decay was probably due to the lower transit temperatures in the N trailers. However, the low O_2 concentrations in these trailers may have contributed to the difference. The relationship of temperature to decay in lettuce is well known, but the relationship of low O_2 levels to decay needs additional study.

Pink rib was not affected by type of trailer, but did increase during 4 days at 50° F. in lettuce from both types of trailers.

Russet spotting and tipburn each developed to an appreciable extent in only one test shipment. Therefore, these data are not presented in table 5. In N trailer 7, 7 percent of the test heads had russet spotting, whereas in the companion MR trailer, 90 percent of the test heads had russet spotting. This agrees with more extensive data from other tests,[8] which showed that low O_2 atmospheres during actual and simulated transit tests reduced the incidence of russet spotting considerably.

Weight (moisture) loss in lettuce shipped in N trailers 13 and 15 averaged 0.44 percent during transit, whereas in two companion MR trailers it averaged 0.80 percent. This difference is significant at the 5-percent level.

Table 5.--Incidence of decay and pink rib in trimmed lettuce heads after shipment in liquid nitrogen-refrigerated and conventional mechanically refrigerated trailers

Time of examination	Trailer type[1]	Incidence of--	
		Decay[2]	Pink rib[2]
		Percent	Percent
Arrival..................	N	2.3	14.6
	MR	2.8	19.4
4 days after arrival[3].....	N	14.4	23.6
	MR	24.3	36.8
Statistical significance:[4]			
Trailer type (T)..................		*	NS
Examination (E)..................		**	**
T × E..........................		*	NS

[1] N, liquid nitrogen refrigeration with low O_2 atmosphere; MR, conventional mechanical refrigeration with normal atmosphere.
[2] Condition sufficiently severe to be considered objectionable by consumer. Decay analysis based on 6 paired shipments; pink rib analysis based on 2 paired shipments because this disorder only appeared to appreciable degree in 2 test shipments. See text for explanation of statistical analyses.
[3] Held at 50° F.
[4] NS, not significant; *, significant at 5-percent level; **, significant at 1-percent level.

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[8] See footnote 1, p. 1, and footnote 4, p. 7.

DISCUSSION

A study by Stewart and others[9] showed that russet spotting was significantly reduced when lettuce was shipped to midwest and east coast markets under a low O_2 atmosphere. One of the modified atmosphere trailer types tested in that study derived both its refrigeration and atmosphere modification from liquid nitrogen. Although russet spotting was reduced in this trailer because of the low O_2 atmosphere, decay was increased because of inadequate refrigeration of the load. Temperature profiles and average load temperatures in these N trailers were poor because of inadequate air circulation. These trailers had no fans but depended on convection and the release of nitrogen for air movement within the load compartment.

These N trailers have since been modified by installing a low-velocity pneumatic fan powered by nitrogen at the front of the trailer. The modification also includes a nitrogen vaporizer within the floor structure of the trailer. As liquid nitrogen is vaporized under the floor, the resulting nitrogen gas provides the power to activate the pneumatic fan. This process also provides some additional refrigeration to the lower layers of the load.

The modifications made in these N trailers improved temperature uniformity and average load temperature greatly, as evidenced in eight test shipments of lettuce to east coast markets during 1967. In these current tests load temperatures averaged 3° lower in the N (36° F.) than in the MR trailers (39°), and temperature variation within the load at the center row averaged 3° and 2°, respectively, in the two types of trailers. The modifications in the N trailers also resulted in better quality of the lettuce at destination than that from previous N test trailers.

Some freezing occurred in five of the eight N trailers tested. Most of this was in lettuce at the top and bottom layers in the rows adjacent to the walls. Further modifications in the N trailers are being made to prevent this injury.

In refrigerating the load compartment with liquid nitrogen, the atmosphere was also modified but not controlled, as indicated by the reduced but nonuniform O_2 concentrations in the N trailers. However, these lowered O_2 levels during transit significantly reduced russet spotting. Additional modifications are planned for the N trailers to prevent dangerously low O_2 levels within the load compartment.

Problems also occur in the MR trailers. Loads from two of the eight trailers tested were lost because the mechanical refrigeration equipment failed. In addition, one MR trailer apparently had an improperly calibrated thermostat, which caused the load to average 43° F. in transit.

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[9] See footnote 1, p. 1.

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